Chapter I Lightning Measuring Apparatus

1. Introduction

As to the apparatus which measures the lightning discharges from the earth's surface, there are a few types and methods, for example, the one which measures the optical phenomena of a discharge, the one which measures the electromagnetic effects of it and the one which uses the physical properties of a lightning channel to know the structure of it - the radar method -, however, we shall describe here only an outline of the apparatuses with which we have obtained the data of this paper throughout our thunderstorm observations in several summers.

2. Electromagnetic methods

A statistical examination of duration of a lightning discharge measured on a record of luminosity changes produced by. it shows that the median value of a lightning duration generally amounts to 0.48 sec. (see II 2, Table 3) Moreover, it is not seldom that a strong discharge, continuing itself more than 2 sec., is recorded with a high sensitivity apparatus using electromagnetic method. These discharges with long durations generally hold in themselves high frequency components of radiation fields which can be detected with a UHF-ban radio receiving apparatus.
Accordingly a frequency spectrum of electromagnetic effects of a lightning discharge usually spreads out a wide range no less than $1 - 10^{10}$ cycle/sec. This makes it very difficult to record the electromagnetic effect of a lightning discharge with one apparatus throughout the whole range of the frequency spectrum. This is the reason why we prepared two kinds of electromagnetic apparatus, i.e., the electrostatic field meter covering the frequency range 0 - 1 kc/sec and the apparatus which records a rapid component of electromagnetic field change produced by a lightning discharge and which covers the frequency range 0.3 - 100 kc/sec. We shall call the latter apparatus "the short range waveform recorder of atmospherics, because the latter has essentially the same construction as that of an ordinary waveform recorder of atmospherics being propagated more than several hundred kilometers along the earth's surface.

(A) Short range waveform recorder of atmospherics

As already mentioned, there is no essential difference in measuring principles between a short range waveform recorder and a long range waveform recorder. The only differences between them are the the gain and the time-constant of the amplifiers of which they are constructed. As to the time-constant of a waveform recorder amplifier, it must be selected so as to fit the purpose of the observation, i.e., how fast electromagnetic field changes

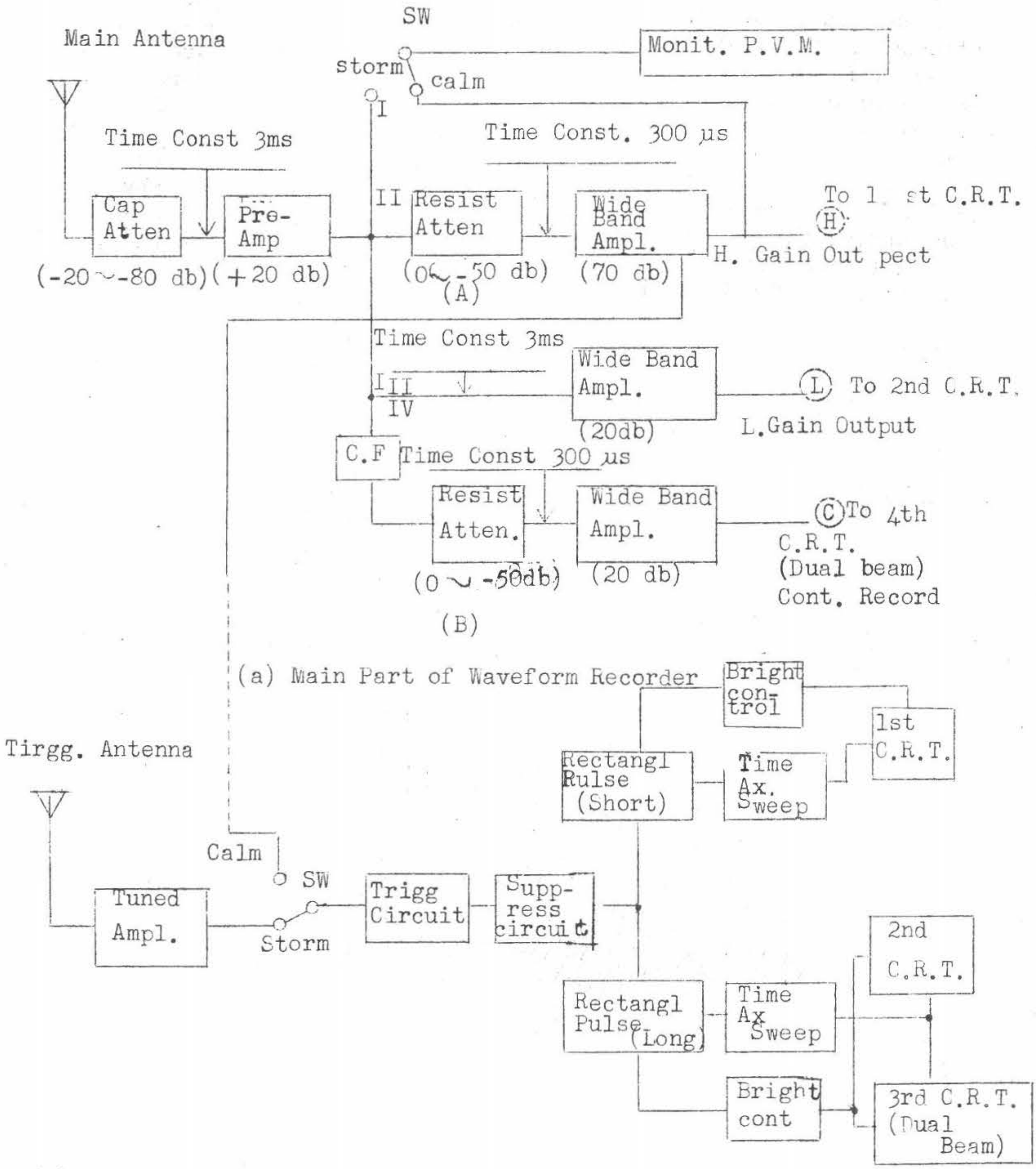
must be measured. It must always be larger than the duration of the field change to be measured. As to the gain of the amplifier, a short range waveform recorder usually concerns a lightning discharge within the range of 60 ~ 70 km. from the observation station.
Accordingly the magnitude of an electromagnetic field change to be registered, in this case, is usually so large enough that it can easily be recorded with an amplifier of comparatively lower gain than that of a long range waveform recorder. The relation between the waveform recorder gain and the distance of a lightning discharge from an observation station, usually applied to an actual thunderstorm observation, is indicated in Table 1.

Table 1.

Resultant gain of the waveform recorder	Distance from a lightning discharge
From -30 to -10 db.	Less than 5 km.
From -10 to 0 db.	From 5 to 10 km.
From 0 to 10 db.	From 10 to 20 km.
From 10 to 20 db.	From 20 to 40 km.

* Effective height of the used vertical antenna is 2m.

Fig. 1.

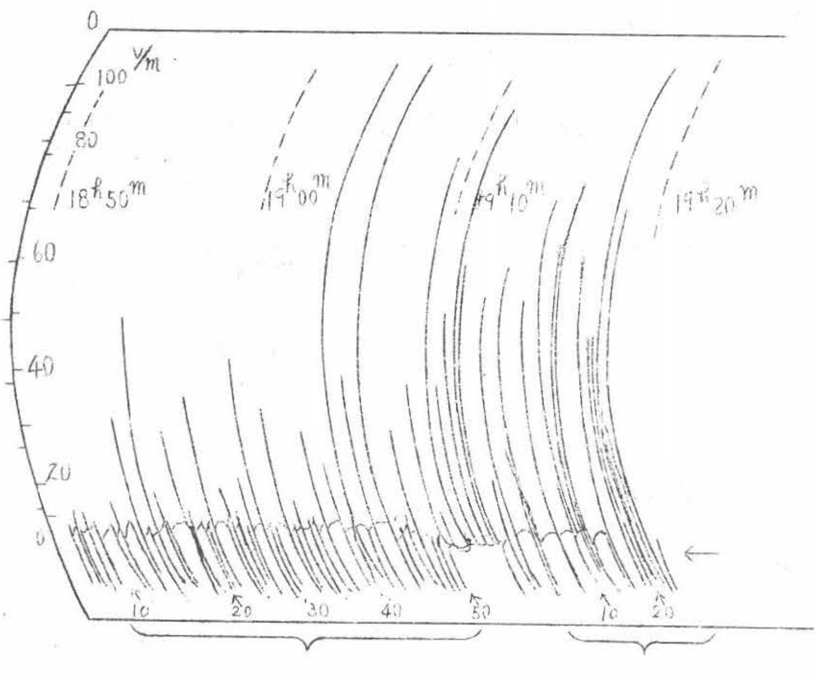


(a) Main Part of Waveform Recorder

(b) Accessory Part of Waveform Recorder

After the completion of construction of the short range waveform recorder in several years ago (1) the apparatus was subjected to many improvement in every summer. Fig. 1 shows a block diagram of the apparatus at the end of the summer in 1959, the main part of which is illustrated in Photo. 1. An atmospheric input induced in the main antenna (see Fig. 1 (a)), after passing through capacitance attenuator and pre-amplifier, is divided into four branches. Branch I is connected with a change-over switch to a peak-voltmeter indicated in the figure on an occasion of nearby thunderstorm observation, and a peak value of each rapid electromagnetic field change due to a lightning discharge is recorded with an ink-writing amperemeter, an example of whose record is illustrated in Fig. 2. In an occasion when there is no thunderstorm nearby surrounding the observation station, the peak-voltmeter is connected to the high gain Branch II, and we can know, in this case, the outbreak of a thunderstorm

Fig. 2.
1956. 8. 16.



occurring at distances up to about 100 km from the station, by monitoring the indication of the P.V.M. subiected to an adequate gain. In the case of a nearby thunderstorm on the other hand, we can adjust the amplitude of a waveform produced on the screen of a recording C.R.T. to an appropiate value by monitoring the swings of P.V.M. Branch II and III are connected to C.R.T. I and II respectively, which are triggered by the accessory part of the apparatus (Fig. 1 (b)). Using these two C.R.T's we can get two wave forms corresponding the same part of a discharge at the same time, i.e., a low gain waveform and a high gain waveform. The difference between the gains at the output H and L can be controled by adjusting a resistance attenuator A up to 50 db. Luminous spots of C.R.T. I and II are subjected to a brightness modulation, and the singly sweeped waveforms are represented on the screens of the respective C.R.Ts at the instant when an atmospheric arrives at the main main antenna of the waveform recorder. We shall call this representation hereafter a trigger waveform. The accessory part of the recorder is represented in a block diagram of Fig. 1 (b). In a calm condition, when there is no nearby thunderstorm, the output from the main amplifier is usually connected to and operates the triggering circuit. In a thunderstorm condition, however, the input to the circuit is altered with a change-over switch, and an atmopsheric disturbance induced in the triggring antenne, amplified by a tuned type amplifier, operates the cricuit. This trigger technique using a separated triggering antenna with tuned type amplifier partly has made it possible to record a desired part of rapid electromagnetic field changes due to a lightning discharge. For example, we can obtain with this technique a trigger waveform representing a ground discharge from the first leader to the following first return stroke or representing it from the first return stroke onwards, according to the purpose of an observation. Tuning frequency of the radio receiver are selected at 100 kc or 1 Mc or 10 Mc. Every when an input to the triggering circuit exceeds a certain level adjusted to an adequate magnitude, a trigger pulse is formed in the circuit immediately, which after passing through the suppressor circuit, builds up two rectangular pulses with long duration (40 ms) and short duration (1 or 2 ms) respectively. These long and short rectangular pulses operate the brightness modulation, which combined with the two respective single time sweeps, initiated by the trigger pulse, completes the process to produce the two trigger waves on the respective C.R.T. Thus a low gain waveform with 40 ms sweep and a high gain waveform with 1 or 2 ms sweep, both corresponding to the same part of a discharge, are represented once on the screens of C.R.T. II and I respectively. These trigger waveforms are photographed frame by frame by a 35 mm camera and a 16 mm cine camera mounted beforehand of C.R.T. II and I respectively. The film mounted in 16 mm cine camera is advanced frame by frame every time after photographing a waveform automatically. When there exists no nearby thunderstorm, the combination of C.R.T. I and 16 mm cine camera is adopted to obtain a high gain waveform with 1 ms sweep. The time constant of the amplifier in this case is designed to have a value 300 mirco-sec. In the case of nearby thunderstorms the combination of C.R.T. II and 35 mm camera gives a high gain waveform with 2 ms sweep, under the time constant condition 300 micro-sec, and the combination of C.R.T. I and 16 mm cine camera gives a low gain waveform with 40 ms sweep, under the time constant condition 3 ms.* Using this technique we can obtain two simulaneous records of waveforms, triggered by the same pulse, i.e., a high gain waveform representing the fine structure in the period of 2 ms beginning from the trigger moment of, and a low gain waveform representing the rough structure in the period of, 40 ms beginning from the same moment. Fig. 3. shows a pair of trigger waveforms representing a ground discharge, in which (a) represents the fine structure of the field change in the intial part of the first leader, and (a') the rough structure of the same discharge from the initial part of the leader to the end of the following first return stroke.

The suppressor circuit indicated in Fig. 1 (b) is introduced to avoid the waveform being photographed multiply, i.e., to limit the C.R.T's being triggered many times by successive radiation pulses involved in field changes due to a lightning discharge. After a trigger pulse once has passed through the circuit, the gate of the circuit is closed by an electromagnetic relay immediately following to an electronic suppressing, and this will not be recovered until the film mounted in the camera advanced by one frame. Through this technique a multiple exposure can be avoided completely, how strong radiation pulses may arrive at the trigger antenna, after the trigger has started.

Branch IV is connected to a system to obtain a continuous record of waveforms on a running 16 mm film. The time constant of the system is designed to have a value 300 micro-sec. The output of the system is lead to an element of the dual beam C.R.T. IV. Under daytime conditions, atmospheric waveforms and electrostatic field changes, or under nighttime conditions when lightning luminosity changes are observable, atmospheric waveforms and luminosity changes, are reproduced on the dual beam C.R.T., and recorded on a running 16 mm film of 100 ft. length. We shall call these records a cintinuous waveform (CW). Fig. 4. is an example of a continuous waveform recorded under a nighttime condition and represents a ground discharge with double strokes.

*This interchange of the two recording C.R.T's is performed with another change-over switch not represented in the figuve for the sake of simplicity.

Fig. 3. (1959. 8. 18. 20h 8m)

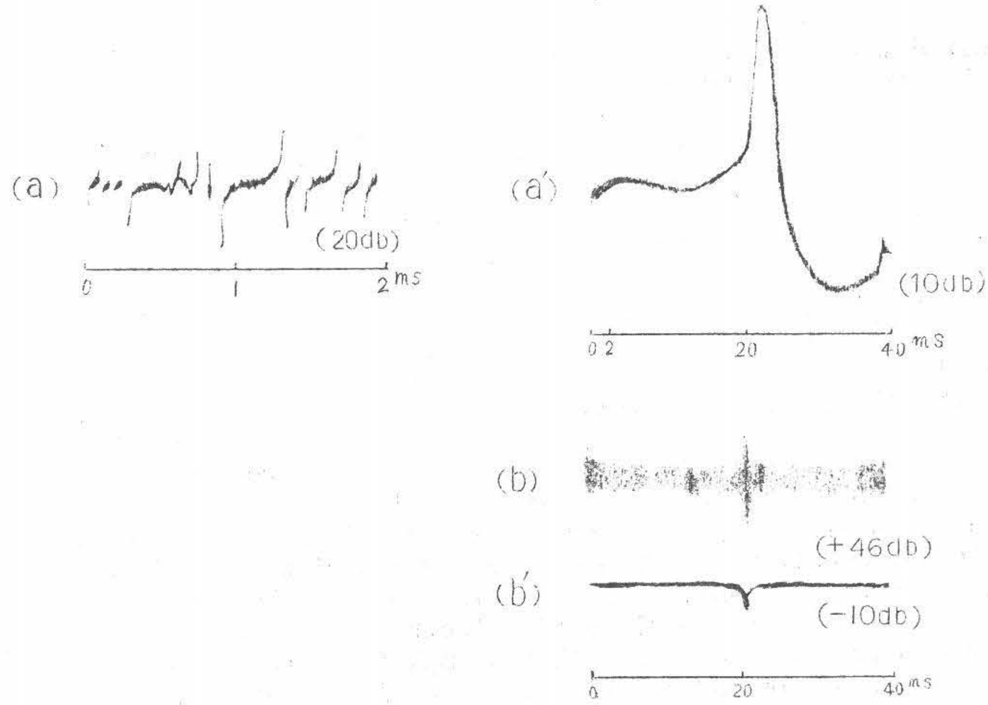
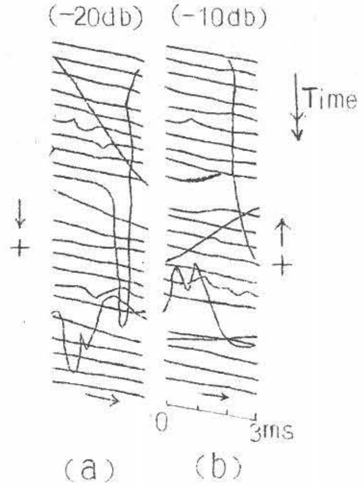


Fig. 4. (1959. 8. 19. 19h 31m)



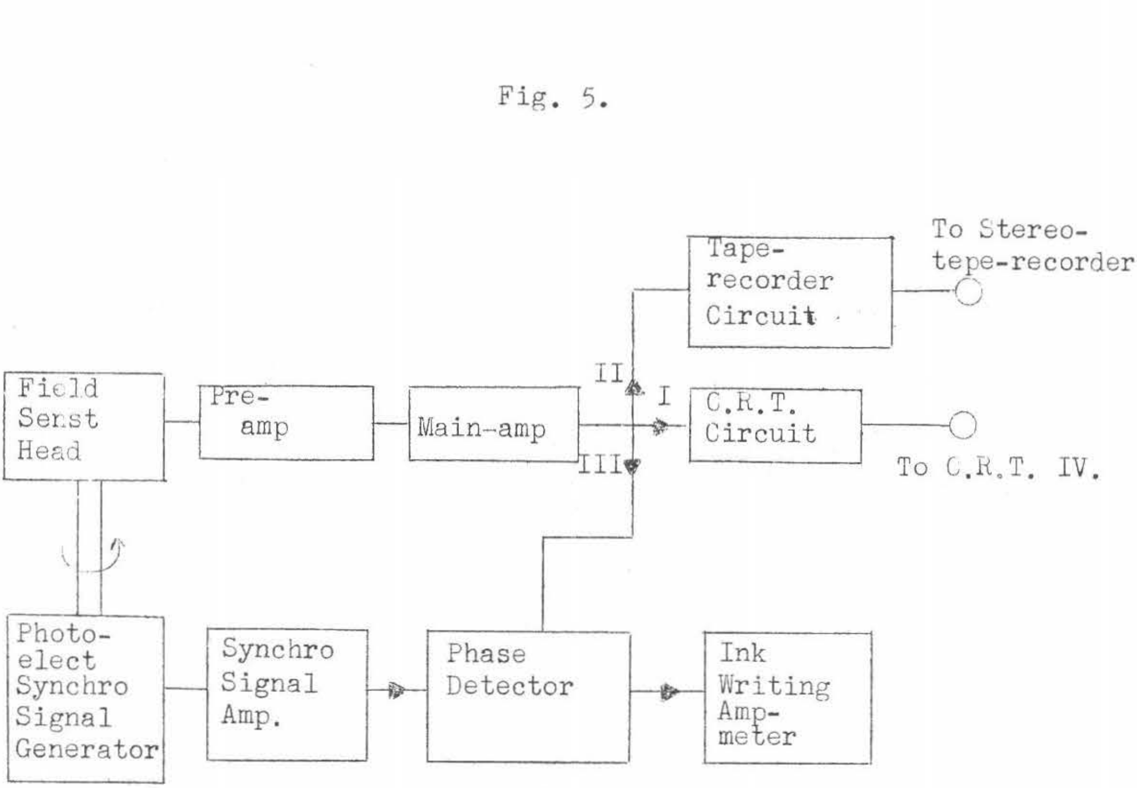
(a) represents the waveform of lightning luminosity changes, which will be touched later on once more, (b) the atmospheric waveforms corresponding to them. The time seep of these two waveforms (a) and (b) are both 3 ms, and the sweeping are synchronized with each other, so that we can recognize a clear light pulse to correspond to a clear pulse of electrostatic field-change. As indicated by arrows in the figure the positive directions of the two waveforms are reversed with each other and the time advances from the upper end of the figure to the lower and of it. The time sweep runs from left to light, as it is indicated by a simple arrow in the figure.

(B) Electrostatic field-meter (2)

This type instrument was first put into a practical use for thunderstorm observations by Malan and Schonland. (3) The electrostatic field in the air, which induces an electrical charge on the surface of field sensitive metal electrodes of the apparatus arranged parallel to the earth's surface is mechanically modulated by rotating a metal shield disk with holes matched to the sensitive electrodes, arranged horizontally just above the electrodes plane. Through this process a DC input to the electrodes proprotional to the electrostatic field intensity is changed into a AC with the amplitude proprotional to it, thus the envelop of the amplitude modulated output will be able to record represents an electrostatic field change whose frequency range spreading from 0 cycle/sec to the carrier frequency.

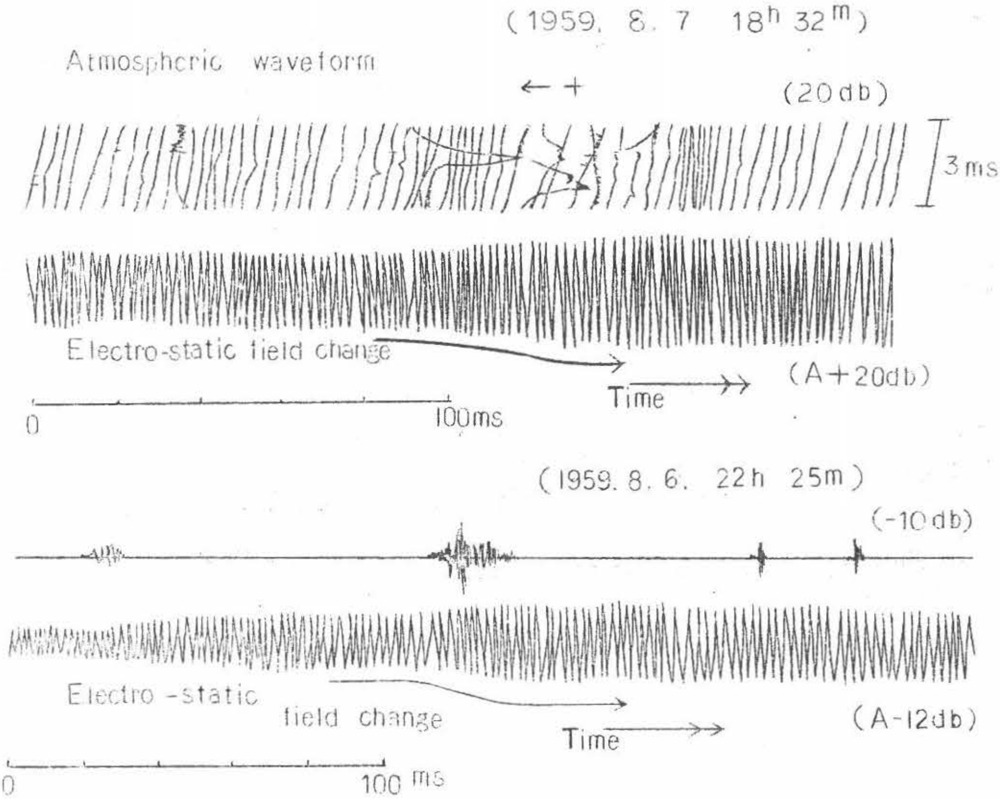
Fig. 5 shows a block diagram of the field-meter, and the field sensitive head and the main part of it are illustrated in photo. 2 and 3 respectively. As the sensitive head has 24 electrodes on its upper surface and the metal shield disk with the same number of holes are rotated at a speed of bout 1800 rpm, so the acrrier frequency becomes roughly 700 cycle/sec. The modulated output from the head is divided into three branches after having amplified to an appropriate degree.

Fig. 5.



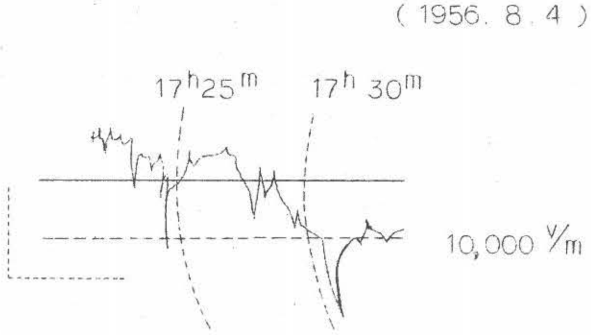
The output of Branch I is fed to an element of the dual beam C.R.T. IV, and recorded continuously on a 16 mm cine film along with the corresponding atmospheric waveforms produced by a lightning discarge under a daytime condition, an example of which is illustrated in Fig. 6. (a) representing a case of a cloud discharge. The upper half shows an atmospheric waveform and the lower half the electrostatic field change corresponding to the former.
The manner in which the electrostatic field varies is represented by an envelop of the lower record, and the side of the envelope being to be measured is indicated with an arrow in the figure.
The Branch II is led to an element of a stereo-tape-recorder.
The other element of the tape-recorder is connected to the output from a MF atmosoheric radio noise receiver under a day-time condition, or to the output from a lightning luminosity change recorder under a night-time conditon. Fig. 6 (b) shows a result play-backed from a magnetic tape-record onto a 16 mm cine film running continuously and gives an example of a simultaneous record of electrostatic field changes and lightning luminosity changes produced by a cloud discharge under a night-time condition. The upper half represents a lightning luminosity changes, and the lower half the record of the corresponding electrostatic field changes, whose side being to be measured is indicate by an arrow

Fig. 6.



As these two methods of recording the field changes using a C.R.T. or a tape-recorder are not convenient for monitoring the very slow field changes produced by the movement of a thundercloud, Branch III, is introduced for this purpose, which drives an ink-writing ampere-meter with a time constant about 0.1 sec. As the output from the main amplifier is subjected to a AM and consisted of a AC with frequency about 700 c/sec, whose amplitude is proprotional to original electrostatic field intensity, so the output itself can not drive a DC ampere-meter. For this purpose the output must be dected so as to drive an ampere-meter and to coincide the deflection of the ampere-meter with the instantaneous polarity of the electrostatic field. To perform this it is needed to generate a reference AC, being of the same frequency as the AC output of the main amplifier, and synchronized with it, and to force the output from the main amplifier to pass through the detector during a specified half cycle of the reference AC. This is performed by a phase detector indicated in the figure. There are many ways possible to obtain a synchronized reference AC, however, the following technique is adopted on behalf of its stable performance. A rotation screen with the same number of slits as the field sensitive electrodes, is attached to the rotation axis of the head, and a light beam from a pilot lamp is interrupted by this rotating slits, through which the light pulses synchronized with the main output are generated to operate a small photo-electric vacum tube. The AC output from the photo-electric tube is fed to the phase detector as a reference signal, and control the timing of opening the gate of the detector. An example of a electrostatic field change recorded with an ink-writing ampere-meter is illustrated in Fig. 7.

Fig. 7.



Generally speaking this type of an electrostatic field-meter described here has a very low sensitivity compared with that of an atmospheric waveform recorder type instrument, and in addition, the field-meter is usually inverted, sensitiv electrodes downwards, to avoid being wetted by rain during a thunderstorm observation, so that the recordable lower limit of this instruments is only about 5×10^2 volt/m. This means that the recordable limiting range of this instrument is only 10 km for a ordinary lightning discharge, and can not exceed 15 km even for a very strong discharge. To over-come this defect an antenna metal plate insulated from the earth by teflon insulators is attached close to the head in parallel to the rotating metal shild disk, and further, a vertical antenna with a height of 4 m, being insulated carefully, is connected to the plate. If this antenna system is insulated from the earth carefully, so as the leakage resistence of the system to have a value larger than 10^{10}ohms, and hence, the time-constant of the system to attain to a value lager than 1 sec, an electrostatic input induced in the antenna system is roughly smoothed out by the mechanical modulation of the head. Through this procedure the electrostatic component of an atmospheric field change is separated from the radiation component and modulated at the same time. The field-meter with an antenna system can resister a lightning discharge more than 30 km distant from the station, because the input to the sensitive head is increased by the influence of the antenna system very much, provided the time-constant of the antenna system is not reduced to a low value by a humid air resulting from a rainfall. Fig. 6 (b) illustrates a record obtained at the time when an antenna system was attached to the head.

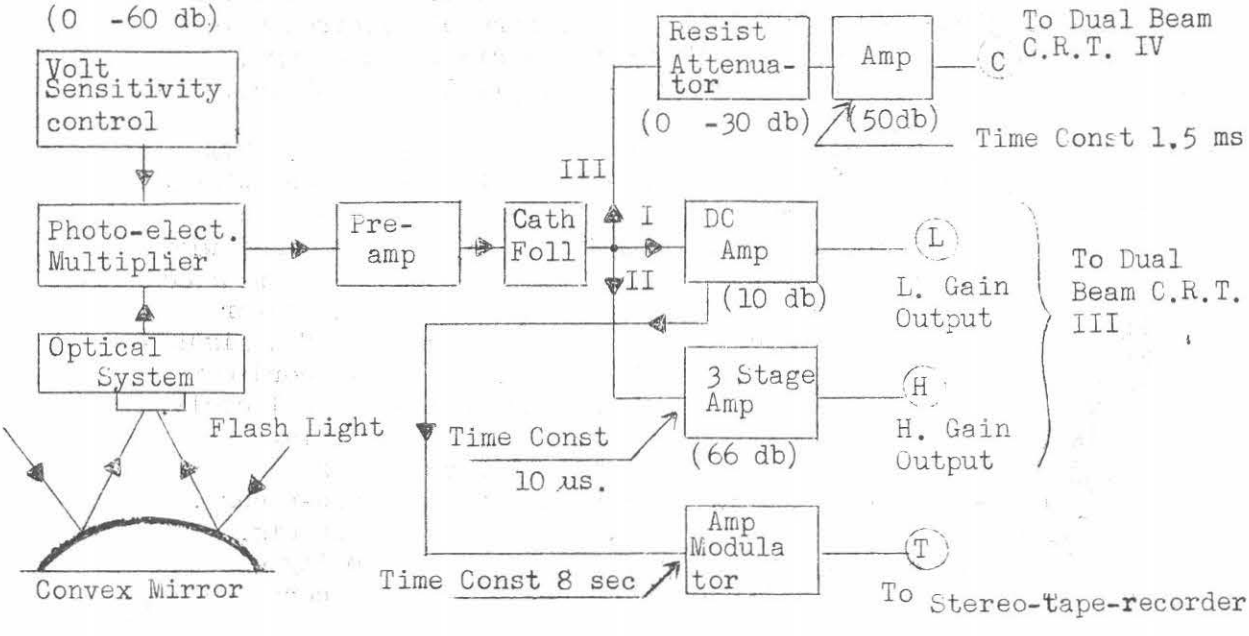
3. Optical methods

The photographic method has been a powerful means of the sudy of lightning discharge mechanisms since the invention of photography,(4) because a lightning discharge always acompanies strong luminous phenomena. Many of the present knowledge concerning the mechanims of a ground discharge has really been obtained with this photographic method. However, it is in no way easy to obtain a reliable photograph of a lightning discharge, which gives us a new knowledge about the discharge mechanism having not been cleared till to the present. For example, a photograph an α type stepped leader has not been obtained in the open field till to the present in the world except for the plateau zones surrounded by mountains like Johanesburg in South Africa, New mexico in the United Stated, and Switzorland. This indicates clearly that the most essential point to catch an accidentally appearing lightning in a photograph is to select a proper place and to have a proper chance for photographing it. Accordingly it is very important to get an observation station at a place, where the humidity is low and the occurrence frequency of thunderstorms is very high, if possible, especially after the sun-set. The method of recording the luminosity changes produced by a lightning discharge with a photo-electric instruments gives us by no means a direct and clear knowledge about the mechanism of the discharge however, it can register the luminosity change due to a curtain lightning more than 40 - 50 km apart from the station, so long as it appears after the sunset and the light reflected by a cloud body is observable by our naked eye. In contrast to the former photographic method, the latter photo-electric method gives us the chance to record a lightning discharge under very bad condition, and thus has a very wider applicability than the former. We shall describe the details of these two instruments in the followings.

(A) Lightning luminosity recorder(5)

The luminosity change caused by a lightning is converted into an electric change with a photo-electron multiplier tube, and the converted change, after amplified, is recorded in several ways. Fig. 8 shows a block diagram of the instrument. Light from a lightning reflected by a horizontal convex mirror enters to a lens system and the image of it is focused on the photo-sensitive electrode sureface of a multiplier tube. Through this procedure the luminosity change of a lightning is converted into an electric voltage change proprotional to it. Light collecting action of a convex mirror makes it possible to catch all lightning discharges whose angles of elevation are larger than 30 degrees. The sensitivity of the multiplier tube can be changed from 0 to-60 db in 10 db steps by adjusting the supply voltage. In addition, it can also be changed by adjusting the iris of the lens system or by attaching suitable density filters to it. The output from the multiplier tube, with amplitude proprotional to the incident luminosity, is fed to the main part of the instrument after passing through a pre-amplifier and a cathode-follower. Here the track is divided into three branches. Branch I and II are connected to a low gain DC amplifier and a hith gain amplifier with time constant 10 micro-sec respectively and then led to the respective element of the dual beam C.R.T. III. As the C.R.T. III is triggered by a trigger pulse from the short range, waveform recorder, a part of the luminosity changes caused by a lightning is recorded on a frame of a 35 mm film in two ways, synchronized with the record of an atmospheric waveform, i.e., the one giving a low gain record showing the rough structure of luminosity changes, and the other giving high gain record showing the fine structure of weak part of a lightning flash.

Fig. 8.



The difference of the gain between these two is designed to have the value 56 db, and the length of the trigger sweep can be varied by a change-over switch in two steps, i.e., 1 or 40 ms. Fig. 3 (b) and (b') illustrate the waveforms of luminosity changes synchronized with a short range atmospheric waveform (a'), in which (b) represents the record of high gain and (b') the record of low gain. Both these two indicate each a clear light pulse at the same position on each time sweep axis, which corresponds to an atmospheric pulse caused by a return stroke in the waveform (a). An appreciable deflections distributed throughout the whole sweep of the luminosity waveform (b) in the figure come from the high frequency noise of the multiplier buve itself, which is amplified by the high gain amplifier to a recordable dgree. A record of the high gain track thus gives a luminosity waveform of an incident light pulse amplitide modulated by the noise of the multiplier tube, so that it is of little meaning to amplify the output of a multiplier tube too much. This may be an essential defect of a multiplier tube, when applied to the measurement of the low luminosity changes. Therefor the technique using a multiplier tube seems not to be able to record the fine structures of a lightning.

After passing through resistance attenuator and amplifier with time constant 1.5 ms, the Branch III is connected to an element of the dual beam C.R.T. IV and the lightning luminosity change is recorded along with the corresponding atmospheric waveform on a running 16 mm film continuously, when a thunderstorm appears after the sun-set. Fig. 4 (a) shows an example of this record and has saw-teeth sweep synchronized with the record of the corresponding atmospheric waveform (b). If we control the sensitivities of these two records adequately, it is possible to give the waveform of a lightning luminosity change a very similar structure as that of the waveform of electrostatic component of the corresponding atmospheric field change.

A branch separated from the DC amplifier is subjected to AM.

In the case of a night-time thunderstorm observation, this branch is connected to the second element of the stereo-tape-recorder and the lightning luminosity change is recorded together with the electro-static field change simultaneouwly. As the carrier frequency of this amplitude modulator is about 4 kc, and the time constant at the input to the modulator is 8 sec, long enough compared with the duration of a lightning discharge (1 - 2 sec. at most), so the tape-record can cover a wide frequency range, spreading from 4 kc to 1 cycle. This enables us to measure a weak continuous lightning lumirosity that often lasts more than several hundred ms without any serious error. An example of this tape-record, play-backed on a 16 mm cine film, is illustrated in Fig. 6 (b), in which the upper half represets the luminosity change and the lower half the electrostatic field change corresponding to the former. We can clearly recognize two short continuous luminosities in the upper record appearing at those points where the lower record indicats an appreciable electrostatic field change.

(B) Lightning flash resolving camers

One of the most direct method of analyzing the structure of a lightning dishcarge is to photograph it by a special camers. A still photograph of a lightning flash gives us the informations about its from, its size in two dimensions, its direction of occurrence, etc. If we succeed to photograph a lightning flash of a ground stroke at two different stations simultaneously, we can fix the position of it by triangulating on a map. However, when the fine structure of a lightning flash must be made clear, especially when the progressive character of it must be analyzed, it becomes necessary to obtain a photograph of a lightning flash resolved with respect to time. A lightning streamer generally has a very short life time. For example, even a stepped streamer, i.e., one of the slowest streamers, has a median value of life time amounting only to 15 ms. If we intend to catch the progressive character of a stepped leader in 10 frames of a cine photograph, a camera speed of more than 10^3 frame/sec will be needed. Moreover, as a lightning discharge is a very incidental phenomenon, and has a short time duration, it is by no means easy to photograph lightning flashes with a high speed cine camera, unless the film mounted in it is driven endlessly. If the film is not endless, the wast of films will come out tremendous. For this reason the resolving of a lightning flash is usually performed by moving a flash image along the surface of a photo-sensitive film. If the movement of a flash image is performed by endless sweep orrepeated sweeps, we can wait the occurrence of an incidental lightning by opening the camers shutter and giving the photographic image a motion for several minutes under a night-time condition. The method of image sweep can save the photo-sensitive film very much and is suited for a prectical thunderstorm observation. There are several methods possible to give the photographic image a sweep motion, i.e., the method to move a camera lens system, the method to move a sensitive film, the method to move a image by rotating a mirror or a prism, and the method to rotate a camera system. Of these, the method to rotate two lenses parallel to a photo-sensitive plate is one of the oldest and the most convenient method, so that we have constructed two cameras of this type, for the sake of their convenience for a practical thunderstorm observation. We shall call these two as the Boys' camera. Photo 4. shows one of our low speed Boys' camera. A cabinet size photo-sensitive plate is mounted on back side of the camera. Two lenses of Tessor type, f = 75 mm, and F/3.5, are mounted on the front face of the camera. As the distance between these two is 56 mm, the time resolving power of this camera is roughly 150 micro-sec, provided the rotation speed being kept at 360 rpm. The camera is not suited for a long run at a rotation speed larger than 800 rpm, becaus two large precision ball bearings are mounted inside of the camera to improve the accuracy of photography. Photo. 5. illustrates an example of a flash photograph obtained with one of these two low speed Boys' cameras. Many whit circles in the photograph come from the town lights surrounding the station. We can see a weak silhouetter-like trace of a stepped leader running parallel to a strong return stroke to the right-upper portion of the white circle.

The low speed Boys' camera described above has a small size and can be turned at ease to the direction of lightning discharge, if mounted on a carrier. Therefore the camera is very fitted for the observation of a cloud discharge in out-doors except for the time of a heavy rainfall. As the angular coverage of this camera is less than 50 degrees, it is very difficult to catch lightning flashes occurring successively in various directions through a violent period of a thunderstorm, especially when the observation station is surrounded by a heavy rainfall. In this case it is necessary to provide a camera covering all directions, and moreover it should have a high time resolving power to record the fine structure of a lightning flash appearing close to the station. Fig. 6 illustrates a camera designed for this purpose, the light from a lightning flash reflected by a dodeca-faced rotating mirror enters one or two of the eleven 35 mm cameras surrounding the rotating mirror, and thus the image of the lightning flash is recorded by the respective cameras corresponding to the direction of the flash occurrence. The sweep of an optical image in the respective camera has an analogous waveform of that of a C.R.T. oscillos cope. In this camera, the angular range, covering 330 degrees of the horizontal directions, is divided into 11 sections, and the each section is covered by a respective 35 mm camera surrounding the mirror, therefor practically no dead angle is left in this angular range of 330 degrees. This enables us to catch nearly all the lightnings occurring at random in all directions. As the image sweeping is performed by a rotation motion of a mirror, the speed of it is made twice as much as the rotation speed of the mirror, and the time resolving power of the camera amounts to about 25 micro-sec provided the rotation speed being kept at 600 rpm according to our experimental measurement. The limiting value of the time resolving power of this camera is about 10 micro-sec, because the rotating mirror is designed so as to keep their faces practically flat up to 1500 rpm. The film mounted in each 35 mm camera can be advanced frame by frame at one time by pulling handle illustrated in Photo. 6. so that the frame change can be made without any difficulty even in a darkness. The lenses with 50 mm focal length adopted here have apertures F/1.2 or 1.5, as it has been cleared out that the aperture of the lens is an essential factor to record the fine structure of lightning flash. The weight of the apparatus is about 100 kg, and is not covenient for to move. The apparatus has been arranged in a small square box for thunderstorm observation with glass windows in three directions during the period of our thunderstorm observation in every summer, and the observation box has been mounted on the roof of a building of Telegraph and Telephone Office at Maebashi-City, one of the most thunderstorm frequent districts in our country, to obtain a good view of flashes and to increase the chance of photographing them. Photo. 7 illustrates an example of a air-flash photograph recorded with this apparatus. As the streamers illustrated in the figure belong to a β type stepped leader, the exact structure of individual step streamers are not discernible in this photograph,

Photo. 1

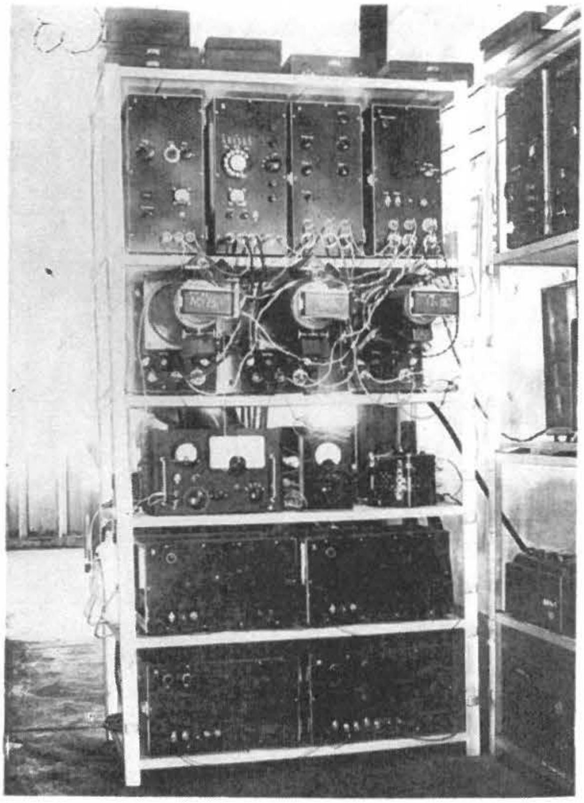


Photo. 2

Photo. 3

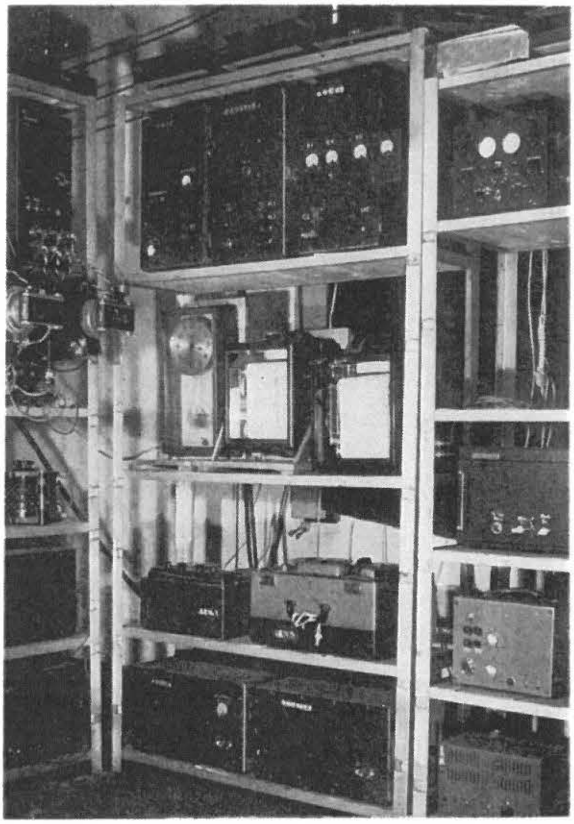


Photo. 4

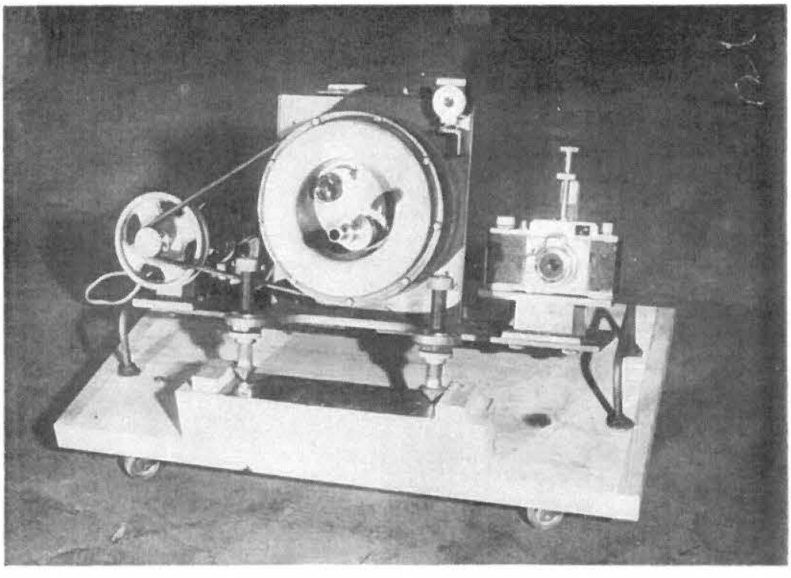


Photo. 5

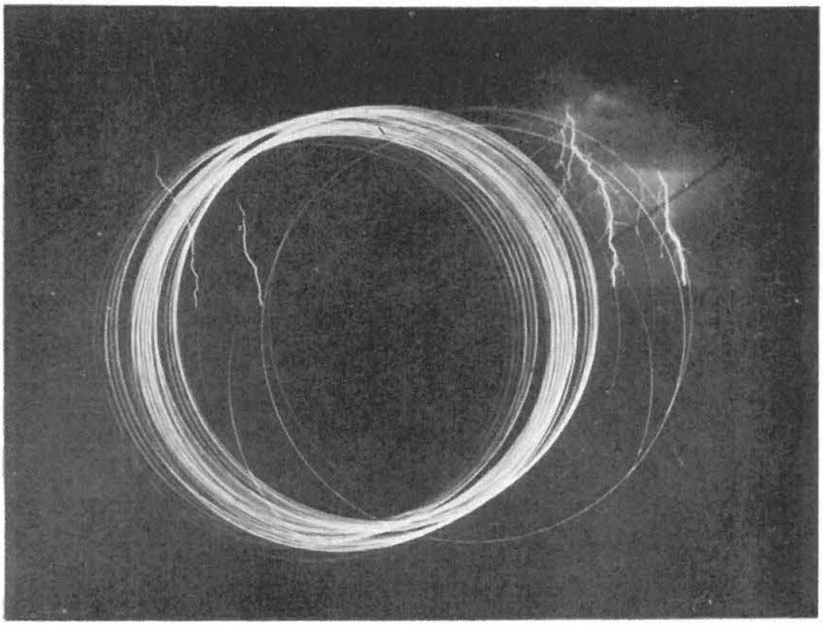


Photo. 6

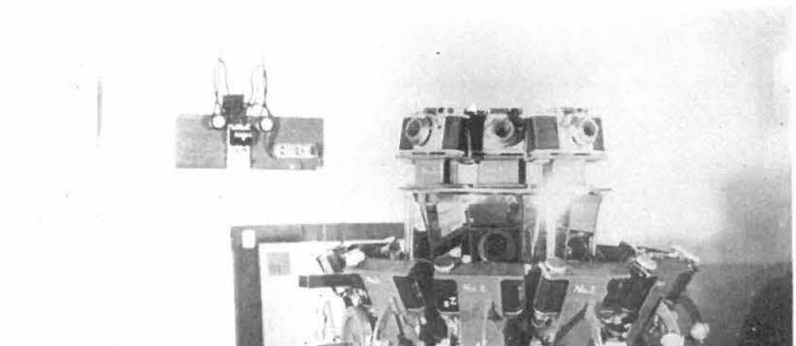
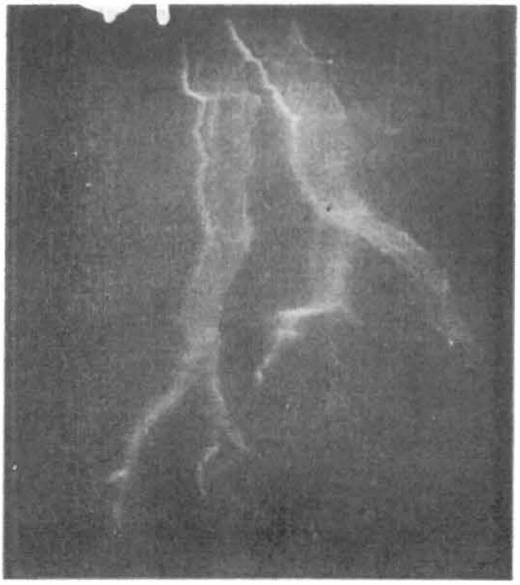


Photo. 7



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